SCIENTIA AC LABORE

University of Queensland

PAPERS

DEPARTMENT OF PHYSICS

Volume I 1948 Number 5

The Application of Atomic Energy

(JOHN THOMSON LECTURE, 1947)

BY

H. C. WEBSTER, D.Sc., Ph.D., F. Inst. P.

Price: One Shilling and Sixpence

PUBLISHED AS AN ORIGINAL PAPER BY THE UNIVERSITY OF QUEENSLAND

DATE OF PUBLICATION
April, 1948

DEPARTMENT OF PHYSICS

VOLUME I 1948 NUMBER 5

THE APPLICATION OF ATOMIC ENERGY

By

H. C. WEBSTER, D.Sc., Ph.D., F. Inst. P.

(Published as an original paper by the University of Queensland.)

DATE OF PUBLICATION:
April, 1948

Printed by Watson, Ferguson & Co.
Stanley Street, South Brisbane

THE APPLICATION OF ATOMIC ENERGY

PREFACE.

It is with some diffidence that I come before you to-night, partly because the information which I have to give you is, of necessity, second-hand, and partly because among my distinguished predecessors in this office has been no less a person than the late Baron Rutherford. I was not in Brisbane when Lord Rutherford lectured here, but from the titles of his discourses it is clear that he spoke largely about atomic energy, though perhaps not under that name.

Much has elapsed in the 22 years since Rutherford gave those lectures, and the science of nuclear physics, of which he was the founder and, for so many years, the leader, has developed, from a pleasant academic study, into a major factor in world politics. Those of us who had the privilege of working under Rutherford feel sure that, had he lived, his forceful personality and his essential simplicity and goodness would have contributed to a major degree to the solution of the political as well as of the scientific problems of atomic energy.

ATOMIC ENERGY.

Before proceeding to discuss the application of atomic energy, I should first briefly explain what atomic energy is. *Energy* is a word in common use ; in science it has a special technical meaning, viz., the capacity for doing work—that is, work in the mechanical sense of lifting a weight or something of the sort. Heat, light, sound, electricity are all forms of energy, just as energy is possessed by a moving train, and by a lift at the top of a building. The different forms of energy can all be converted into one another (subject to certain conditions) and we know of no case where energy gained in one form is not exactly compensated for by energy lost in another form. The sum total of energy in the universe is always the same.

Under certain circumstances, however, energy—sometimes light, sometimes heat, sometimes electricity—makes its appearance without the corresponding disappearance of any of the other *common* forms of energy. If one fills a glass tube with *radon* gas and then looks at it in a dark room, the tube will be seen to be glowing with a greenish light. Again, if one measures the temperature of a mass of *radium* with a very accurate thermometer it is found that the radium keeps slightly warmer than its surroundings. Yet, in neither case is there any *obvious* source of the energy.

The various special features of the behaviour of radium, radon and certain other elements are classified under the heading of *radioactivity* and it was through a study of these effects, especially through the work of Rutherford and his colleagues, that the existence of a new form—a new source—of energy was established.

In the course of this study, Rutherford and his colleagues formulated a theory[1] of the structure of the atom which is still, with some minor modifications, accepted to-day.

All matter, that is, any material thing like a lump of metal or a quantity of water or a quantity of air, is made up of atoms. A very large number of atoms go to make up the smallest thing we can see. An atom is something extremely small—if we could measure its diameter we would find it to be about one hundred millionth of an inch across. Yet according to Rutherford's theory, an atom is itself built up out of still smaller things. As a matter of fact, most of the interior of an atom is just empty. In this empty space there are a few small particles, arranged somewhat in the way the sun and planets are arranged. The most important of these small bodies is the *nucleus*, located at the approximate centre of the atom. The remaining particles, the *electrons*, revolve around the nucleus.

It was in the nuclei of atoms that Rutherford found the key to the glowing of the radon tube and the other special phenomena of radioactivity, and it is to sudden changes in the nuclei of vast numbers of atoms that the explosion of the atomic bomb is due.

According to present-day views, there is, locked up in the nucleus of each atom, a very considerable quantity of energy. This is a conclusion which is arrived at from Einstein's theory of *relativity*[2], a theory which has been proved to be correct by a number of careful experiments. According to relativity theory, anything that has *mass*—or, to make it simpler, let us say anything that has *weight*—must also possess energy, and the amount of energy it possesses is proportional to its weight. Now, if we calculate the energy associated with each part of an atom, from its weight, we find, in the nucleus, a large *excess* energy, which we cannot account for in any simple way. This excess energy possessed by the nucleus is what is usually called *atomic energy;* we should really call it *nuclear* energy, but the term atomic energy has been generally adopted.

If a nucleus were to lose all its atomic energy it would cease to exist. So far, we have never detected a nucleus ceasing to exist, but definite experimental evidence of the annihilation of electrons has been obtained. Two electrons (or, more accurately, one electron and one positron) sometimes come together and both vanish ; energy is then set free as predicted.

To give you an idea of the amount of energy associated with the nucleus I have roughly calculated the energy which would be liberated if all the nuclei in a pound of water were annihilated. It works out at over ten thousand million kilowatt-hours. A kilowatt-hour is the unit used on electric light meters, and ten thousand million of them would supply all Queensland's needs for electric power for some years.

So far, however, we have been only able to set free a very small part of the atomic energy which theory says is available. Such a liberation of part of the atomic energy accounts for the energy that comes from radium and it accounts also for the more dramatic release of energy in the atomic bomb. In all cases where it has been possible to measure the loss of weight which accompanies this release of atomic energy, it has been found to agree closely with what the theory says it should be.

MILITARY APPLICATIONS. I. THE ATOMIC BOMB.

After this preamble, I propose to say a little about the military applications of atomic energy. So much has been said and written about the atomic bomb that it seems almost superfluous to describe again the principle of its action. Let me remind you, however, of the main features[3].

You will remember that the raw material for the atomic bomb is the element uranium. Uranium is a metal, and it has the special feature that its atoms are heavier than the atoms of any other material that is found naturally on the earth. Associated with this great weight, the nuclei of uranium have a special property, the ability to undergo a process called *nuclear fission*[4], which I shall describe in a moment. All uranium nuclei do not possess this property to an equal degree. A certain type of uranium nucleus—known as U^{235}—is much more fissionable than the other two types of nucleus which are found in uranium, viz., U^{234} and U^{238}. I shall for convenience describe the U^{234} and U^{238} as non-fissionable, though they are actually slightly fissionable. In ordinary uranium the three types of atoms occur in the following approximate proportions :

992	atoms	U^{238}
7	atoms	U^{235}
1	atom	U^{234}
1000	atoms	Uranium

To explain the process of fission, I must point out that, on modern theory, every nucleus is built up from the same two types of building blocks, called *protons* and *neutrons*. The only difference between different nuclei lie in their containing different *numbers* of protons or neutrons or both. Thus U^{235} has 92 protons and 143 neutrons in each nucleus, but C^{12} (that is, carbon) has only 6 protons and 6 neutrons. Under certain conditions, a neutron can be split off a nucleus and wander along on its own for a time. Should one of these unaccompanied neutrons meet a nucleus of U^{235}, *nuclear fission* will almost inevitably occur.

In the fission process, the nucleus splits up into two (or more) pieces of roughly equal size. We can think of the nucleus being cleft in two, each part having roughly half the protons and half the neutrons. This cleavage gives rise to the liberation of a considerable quantity of atomic energy. About *one thousandth* part of the atomic energy originally possessed by the uranium nucleus is set free, in fact. This energy is transformed into more ordinary forms ; actually, in the long run, it appears as heat. Nearly, but not quite, all this energy is released the moment fission happens.

Fission represents a vast disturbance of the nucleus and in this disturbance it usually happens that some of the 144 neutrons, which are present to start with, break off and move away on their own. Sometimes two and sometimes three of the neutrons do this. Furthermore, the fragments left after fission—the " half-size " nuclei—also occasionally lose a neutron later. Sometimes this loss does not occur until some seconds or even minutes after fission. In the following I show two typical ways fission can occur :

Nuclear fission

1 nucleus U^{236} gives $\begin{cases} \text{1 nucleus } Ba^{143} \text{ (barium)} \\ +\text{1 nucleus } Kr^{91} \text{ (krypton)} \\ +\text{2 neutrons} \end{cases}$

or $\begin{cases} \text{1 nucleus } La^{144} \text{ (lanthanum)} \\ +\text{1 nucleus } Br^{90} \text{ (bromine)} \\ +\text{2 neutrons} \end{cases}$

or etc.

This detachment of neutrons is a very important feature of the fission process. For each of the neutrons is capable of producing fission in another uranium nucleus. If conditions are right, we have then only to fire one neutron into a lump of uranium, and we immediately produce, say, two neutrons. Each of these in turn produces two more, giving a total of four. Each of these four gives two again, and so on, the number of neutrons mounting and mounting all the time, until a large proportion of the atoms in the uranium are undergoing fission at about the same time.

Each fission, as I have mentioned, leads to the liberation of energy as heat. The fission of a single nucleus would not heat the lump of uranium appreciably, since the heat would be shared by an enormous number of atoms. But the fission of, say, 10 per cent. of all the atoms in the lump of uranium would be a different matter. Since the whole process could occur within a very small fraction of a second, a temperature of several hundred million degrees could be produced, a temperature higher, possibly, than the interior of the sun. This heat, and the blast which it produces, are well-known features of the atomic bomb.

I have mentioned that certain conditions must be satisfied before the atomic bomb will work, quite apart from needing a neutron to start the process. In the first place, it is necessary that nearly all, if not all, of the atoms in the lump of uranium should be of the highly fissionable variety, that is, of U^{235}. Otherwise the neutrons become *absorbed* in other ways, without producing fissions, and the explosion process rapidly peters out. To sort out a large number of uranium atoms into fissionable and non-fissionable varieties is a very difficult and expensive process, but it has, in fact, been successfully accomplished.

However, it is possible to avoid this process entirely by using, instead of the natural element uranium, certain artificial elements, such as the element plutonium, an element whose atoms are even heavier than those of uranium. Plutonium is made from uranium—so the raw material is the same in both cases—but the process involved is quite different. Another suitable material can be made from *thorium*.[5]

List of highly fissionable materials :

U^{235}	(made from uranium)
Pu^{239}	(made from uranium)
U^{233}	(made from thorium)

I shall later on discuss the way these materials are made.

The second condition to be satisfied in order that the bomb should explode is that the lump of uranium, or plutonium, should not be too small. There is, in fact, a *critical size* for the lump. This is, of course, the key to the actual triggering of the atomic bomb. It would appear that the bomb is set off by bringing together two lumps (or perhaps three or four lumps) of plutonium, each lump being somewhat less than the critical size. One can, of course, imagine other ways of firing the bomb, but they are not likely to be so satisfactory.

This arrangement more or less fixes the size of the atomic bomb. For obvious reasons, the exact quantity of plutonium has not been announced, but it seems to be somewhere between 50 and 100 lbs. If we take the higher figure, the energy liberated in one bomb might be as much as a thousand million kilowatt-hours ; more than all the electric power stations in Queensland generate in a year. It is not surprising, then, that the bomb is said to be equivalent to tens of thousands of tons of ordinary explosive like T.N.T.

MILITARY APPLICATIONS. II. CONTROLLED BURNING.

Although the possibility of an atomic bomb was discussed some time before the war, the main interest at that stage was in the possibility of a controlled liberation of atomic energy from uranium, and this ought to be our main interest now, in peace time. Can we then slow down, and bring under control, the chain of events that occur in the plutonium, so that instead of its entire available energy being used up in a small fraction of a second, the uranium maintains itself moderately hot for some time, and allows us to use the heat for operating a steam turbine or something of the sort ?

Such a " taming " of the atomic bomb can, in fact, be arranged[6], though not easily. To understand how this control is operated, one must first understand what happens when we have a lump of plutonium of *just under* the critical size. If a neutron is liberated in the centre of such a lump, the multiplication of neutrons can commence as before. But after it has proceeded a little way, over half of the neutrons produced manage to escape from the lump of plutonium without having had time to produce a fission. It is evident then, that if we have, say, 100 neutrons at any moment and 51 of these escape without producing fission, then even if each of the remaining 49 produces two new neutrons, we shall end up with less than the original 100 neutrons. Actually, of course, 49 fissions give rather more than 98 neutrons, but we can take it as 98 to illustrate the point.

The matter then resolves itself into a question of profit and loss. If more neutrons are lost in a given time than are gained by fissions, then the process cannot keep going, and rapidly dies out. If there is a profit, even if only a very small one, the process builds up.

However, we have been forgetting the neutrons which become detached subsequent to fission.[7] The number of these delayed neutrons is comparatively small—perhaps one per cent. of the total number of neutrons produced in fissions, but they can turn the balance as between a loss and a profit if things are very finely balanced. This is quite important, since the delay in the detachment of these neutrons, which may average several seconds, means that each increase in the number of neutrons takes some time to become effective. If the process depends on these neutrons it thus builds up quite slowly. This delayed emission of neutrons was, incidentally, a key point in the development of atomic bombs.

Further, if we have a lump of plutonium which is being sprayed with neutrons from an external source, and if this lump is very nearly, but not quite, the critical size, then if we bring near it a sheet of lead the lead acts as a *reflector* of neutrons, and a proportion of the neutrons which have escaped are turned back *into* the plutonium. Hence, such a sheet of lead can convert a slight *loss* into a slight *profit*.

Suppose now, the sheet of lead is gradually moved up to the plutonium. Suddenly, the multiplication process starts to work. But the multiplication is not indefinitely rapid, and several seconds may elapse before there are, say, ten million neutrons. Special detectors can be made which register the number of neutrons and when the figure of, say, ten million is reached, they can operate a switch which stops the lead moving up or makes it move away again. In this way the lead sheet can be adjusted to a position which lets the fissions proceed at a steady rate, a rate which we can select at our convenience.

This type of controlled " burning " of plutonium, if we can call it that, has obviously important military applications, for the heat generated by the burning could be used for the propulsion of a vehicle, a ship or an aeroplane. However, it suffers from the drawback that it is obviously an extremely dangerous machine, for should the control mechanism get out of order, it would not take long for the plutonium to become hot enough to destroy everything in its vicinity. Moreover, the neutrons and other rays which escape from the plutonium during and after fission are extremely dangerous to human life. I shall have something to say on this latter aspect later on.

During the recent war, however, many weapons of the automatic type were devised. Pilotless aircraft, you will remember, were used to considerable effect by the Germans, and there is no reason why pilotless submarines and pilotless tanks could not also be used. In such cases, plutonium propulsion would be very useful, for apart from the initial period after launching, a defect of the mechanism could not harm anyone but the enemy. Its most promising application, however, is to long-range rockets, like the German V2's, only bigger. Probably the mechanism of the rocket could be made very simple.

Any missile, or automatic vehicle, using plutonium in this way, would have to carry the critical amount of plutonium. This is probably about 50 lbs., so it does not seem likely that a great many vehicles, ships or aircraft will be powered in this way in a future war, unless vast new deposits of uranium or thorium are discovered.

To make effective use of the plutonium in such a missile, it would have to convert itself into an atomic bomb at the appropriate moment. One can easily imagine a mechanism which would allow this to be done.

ATOMIC ENERGY FOR INDUSTRY.

I do not intend to pursue the military aspect of atomic energy further, because it is hoped that the nations of the world will not squander their limited resources of uranium and thorium in this foolish way. Instead, I propose to pass on to the application of atomic energy in the peaceful pursuits of industry—for operating machinery, heating furnaces, running trains and trams and merchant shipping, and so on.

At the present time, the energy which we use for these purposes is derived from the sun. Some of the energy is derived more or less directly, using hydro-electric power, while the rest is derived from the *stored* energy in coal and oil. Now the sun's heat is derived, as a matter of fact, from atomic energy. In the sun, by some process about which physicists are still arguing, the element *hydrogen* is converted into the element *helium*. Four atoms of hydrogen are required for each atom of helium. Now it is known that the weight of a helium atom is quite a lot less than the weight of four hydrogen atoms, and hence the *atomic energy* must also be quite a lot less. The joining-up of the hydrogen atoms therefore liberates a considerable amount of atomic energy, in fact, *for a given weight of material*, it liberates more than the fission of uranium—about five or six times as much. For each pound of hydrogen converted into helium some 70 million kilowatt-hours of energy would be provided—equal to the energy obtained by burning 10,000 tons or so of coal.

Since about one per cent. of the earth's crust is hydrogen, it is obvious that if we could devise some way of imitating, on the earth, and under our control, the process that goes on in the sun, we should have a practically inexhaustible supply of energy for industry. A great deal of thought has been devoted, and is being devoted, to this problem. It may be that it is an insoluble one, but there are still promising lines of research which have not been fully explored, such as electric discharge in hydrogen gas.

However, for a more immediate solution to the problem of industrial power we must turn to uranium and thorium. I have already outlined a method whereby industrial energy could be obtained from plutonium, and a similar method could be devised if thorium, rather than uranium, were to be used as the raw material. These methods are somewhat dangerous, and since they both require an initial manufacturing process, the electrical energy finally produced would probably have to be sold at a high price.

There is another way in which energy in a form suitable for driving a steam turbine can be obtained from uranium. This is by modification of the process used in the manufacture of *plutonium* from *uranium.*[3]

THE PILE.

If a fast-moving neutron enters a piece of ordinary metallic uranium, it can be absorbed either by a fissionable nucleus or by a non-fissionable nucleus. Since the non-fissionable nuclei, particularly the U^{238} type, are 99 per cent. of the total, the neutron is most likely to be captured by a U^{238} nucleus, other things being equal. But it is found that if the neutron is moving very *slowly* when it enters the uranium, it is most likely to be absorbed by a fissionable nucleus, in spite of the small number of these nuclei. It then produces a fission, and this gives rise to two or three new neutrons, each of which starts off moving quite fast. These new neutrons would tend to be absorbed without producing fission, owing to their high velocity.

To prevent this, however, the uranium can be distributed as small pieces placed at intervals in a large pile of carbon.

```
C C C C C C C C C C C C C
C C C C C C C C C C C C C
C C U C C C U C C C U C C
C C C C C C C C C C C C C
C C C C C C C C C C C C C
C C C C C C C C C C C C C
C C U C C C U C C C U C C
C C C C C C C C C C C C C
C C C C C C C C C C C C C
C C U C C C U C C C U C C
C C C C C C C C C C C C C
C C C C C C C C C C C C C
```

The neutrons produced by a fission in a particular piece of uranium then usually escape from this piece without being absorbed. As they move through the carbon they are slowed down and, if matters are suitably adjusted, by the time they reach another piece of uranium, they are moving so slowly that they have a better than fifty-fifty chance of being absorbed in a fissionable nucleus.

In plutonium factories, matters are so adjusted, by various subsidiary devices, that the number of neutrons maintains itself at a constant level. This means that of three neutrons produced in a fission, one might be used to produce a further fission, one might be absorbed in a non-fissionable nucleus, and the remaining one might escape from the pile, or be absorbed in some other way. (The relative probabilities of the three processes may actually be somewhat different from this.) Each neutron absorbed in a non-fissionable U^{238} nucleus converts this nucleus (indirectly) into a plutonium nucleus. The pile is allowed to operate for a short time, and then it is shut down and the plutonium extracted chemically.

Now, all the time this manufacturing process is going on, heat is being produced in the pieces of uranium. In plutonium factories this heat is transferred to water which circulates over the uranium, and this warm water just runs to waste. But we could in principle obtain energy from the warm water to drive a turbine. The process would, however, be very inefficient. For atomic energy plants for industrial purposes, it is proposed, therefore, to modify this arrangement, and allow the uranium to rise to a much higher temperature, possibly 200° C, so that the energy can be efficiently utilized. This will probably mean using a gas for cooling the uranium rather than water, and it is thought possible that helium could be used to serve two functions ; first to slow down the neutrons in place of the carbon and second to transmit the energy generated by the uranium to the turbine, or other machine to be used to make electrical energy. It is thought possible to operate such a plant at about 40 per cent. efficiency.[8]

Such modification of the plutonium production process may involve, unfortunately, one drastic change. The process may fail to work with ordinary uranium, for certain additional absorption of neutrons may be introduced, which upsets the delicate balance between profit and loss. This trouble can be overcome by mixing in with the uranium a small amount of plutonium obtained from a plutonium factory. Even 0.1 per cent. would probably be sufficient. This fact is not without political significance, for if it is necessary to manufacture plutonium to run an atomic energy plant, additional plutonium could easily be manufactured and stored for use in atomic bombs.

In order to avoid this difficulty it may be necessary to resort to a second alternative. This is to use what is called " *enriched* " uranium instead of ordinary uranium. Enriched uranium has undergone a *partial* sorting-out of atoms into fissionable and non-fissionable. In this way uranium is obtained which has more than the normal proportion of fissionable atoms. Processes which do this partial sorting-out are fully developed in America. This enriched uranium would be of no direct use for making atomic bombs. It would be nearly as difficult to make an atomic bomb from it as from ordinary uranium.

How the eventual plant will be constructed and what the cost of the energy will be, can only be guessed at. A lot depends on whether the plant is to be used solely for the production of industrial electric power or whether it is to have other functions, such as plutonium manufacture, as well. It seems possible that the cost will not be much more than that of electrical energy produced from coal. It might even be much cheaper. This is a crucial matter especially for Britain, where the best coal seams have already been exhausted, and atomic energy seems the only hope for industrial survival.

RADIOACTIVITY.

In considering the military and industrial applications of atomic energy, one is chiefly interested in the colossal amounts of energy that are made available from a small quantity of material. This tends to overshadow the fact that atomic energy has other special features which make it peculiarly suitable for certain special applications.

In my preamble, I mentioned that atomic energy is liberated by radium, radon and the other radioactive materials. This liberation of energy is quite spontaneous, that is, it requires no stimulus from a neutron or anything of the sort, and it is quite unaffected by anything that is done to the radium. We can think of radioactive materials as possessing a surplus of atomic energy, a surplus which they get rid of according to fixed rules. Each particular element has its own rule, and nothing will make it depart from the rule. Radioactive elements can be divided into two groups, the *natural* radioactive elements and the *artificial* radioactive elements. Natural radioactive elements occur in rocks, etc., and one can obtain them merely by chemical processes. Artificial radioelements are made from common elements by special treatments in electrical devices such as the cyclotron[9], or in atomic energy plants (*i.e.*, piles, such as I described previously). An artificial radioelement is usually closely similar to some common element. For example, radio-sodium and ordinary sodium could not be told apart by ordinary chemical tests. Materials like radio-sodium are sometimes called *radioactive isotopes.*[10] Natural radioelements, on the other hand, are usually quite distinct; there is, for example, no ordinary element like radium.

It is a feature of the liberation of energy by all radioactive materials that the energy appears in the first instance in the form of one or more of three special types of rays; rays which we call the *alpha-*, *beta-* and *gamma-rays.* We can produce each of these types of rays by other methods also, but the machinery required for the purpose is extremely large, extremely expensive and cumbersome. It is also rather inefficient; we have to put into it very much more energy than we get out in the form of the desired rays. Consequently, from many points of view the radioactive materials are the only sources of these rays of practical use.

Of the three types of ray, the *gamma-rays* have by far the greatest practical importance. The gamma-rays from many radioactive sources, such as a sealed tube containing radon, are extremely penetrating. If the gamma-rays from such a tube encounter an iron wall two inches thick, nearly a third of the intensity is still found on the other side of the wall. Further, when a photographic film is exposed to gamma-rays, it is fogged, just as it is fogged by exposure to light, or by exposure to X-rays.

These two facts, the high penetration of the gamma-rays and their ability to fog photographic film, are the basis of one of the applications of the rays in industry. If it is suspected that a large piece of metal intended for use in a machine—a casting for example—has hidden defects, which make it liable to break when the machine is working, then it is often possible to check for defects by inserting a tube of radon in a suitable hole, surrounding the casting by photographic film, then after an appropriate interval removing and developing the film.

RADIATION TREATMENT OF DISEASE.

The chief application of gamma-rays is, however, not in industry, but in medicine. They are extremely valuable for the treatment of certain diseases, notably certain forms of cancer. It is interesting to calculate the amount of energy which is actually used in the treatment of a cancer.[11] Rough estimates show that less than one calorie of energy, when administered suitably to the patient, can be sufficient to cure a small localized cancer on the skin. A calorie is about one millionth part of a kilowatt-hour and if, for example, one calorie of heat were imparted suddenly to one's finger, one would hardly notice the rise in temperature. A calorie, then, is quite a small amount of energy.

In distinction to the amazing effectiveness of the atomic energy liberated by radium, other types of medical treatment in which energy is administered to a patient require much greater quantities. Diathermy treatment, or infra-red treatment, for example, involve the use of hundreds of calories in order to produce an appreciable curative effect. The diseases for which these agents are used are, of course, different from the diseases treated by gamma-rays.

The special effectiveness of gamma-rays arises from the fact that they produce within the tissues of the body an effect known as *ionization*, an effect which diathermy and infra-red treatment do not produce. The cure of cancer is directly traceable to the ionization. Of course, just as drugs are harmful when given in excess, so an excessive amount of ionization is harmful. I shall refer again to this danger presently.

Ionization within the tissues of the body can be produced by *gamma-rays*, by *x-rays*, and also by *beta-rays*. Beta-rays are much less penetrating than gamma-rays, and radium beta-rays are cut off almost entirely by a sheet of iron an eighth of an inch thick. The effective penetration of radium beta-rays into the tissues of the body is quite small, not more than an eighth of an inch. Consequently, there is only a limited range of circumstances under which they can be used in medical treatment. It happens, however, that these circumstances occur quite frequently in Queensland, and there are many thousands of people in this State who have been cured of certain complaints that are liable to lead to cancer by means of beta-rays. The small boxes[12] of radium, or *radon*, which are used in such treatments are very compact and much more convenient to transport than x-ray apparatus.

With such exceptional properties, it is indeed unfortunate that radium is such an extremely rare and expensive material. Radon is obtained from radium and therefore it is just as expensive to use. Other natural radioactive materials are also expensive and hard to come by.

Among the artificial radioactive materials are a number which appear to be quite suitable for medical treatments, provided they could be obtained in reasonably large quantities. Indeed, some of these materials have been used in more-or-less experimental treatments over a number of years. The manufacture of these materials has, however, involved complex and exceedingly costly equipment, and they could not be regarded as in any way a cheap substitute for radium, although certain diseases which cannot be properly treated with radium can be successfully treated with artificial radioelements.[13]

The setting-up of plutonium factories, and the projected setting-up of plants for producing industrial energy from the atomic energy of uranium, provide a potential source of vast quantities of radioactive materials, vast, that is, in relation to their radioactive emissions. These materials are the products of the fission of uranium and other fissionable materials. They are to be found in the residues from the manufacturing process. As soon as methods have been worked out for purifying these materials and making them up in a form suitable for medical treatments, it is expected that substitutes for radium will be available at a small fraction of the present prices. This is an important matter, for if one has at one's disposal practically unlimited quantities of radioactive material, it is often possible to devise a better method of treatment than when only restricted supplies are available.

Furthermore, amongst the materials which should be obtainable from the residues from atomic energy plants are certain radioelements, notably radiostrontium and radioyttrium, which possess marked advantages over radium for beta-ray treatments. They are, therefore, of particular interest to us in Queensland.

HEALTH HAZARDS.

I mentioned a little while ago that for a small localized cancer one calorie of gamma-ray energy may be sufficient for a cure. For other cases, the body must receive considerably more than this amount of gamma-ray energy—perhaps as much as 50 calories. It must not be thought, however, that indefinitely large quantities can be imparted without harm. The ionization which destroys the disease also damages the healthy parts of the body and if the dose is too large this damage is irretrievable. For this reason, persons who have to handle radium or radon in their daily occupations must take special precautions. Careful consideration has laid down a tolerance dose which should not be exceeded ; this works out at about one-fifth of a calorie of gamma-rays each working week, distributed over the main part of the body.[14]

This danger was a perpetual worry to the teams developing the atomic bomb, and it is responsible also for the long delay in making available radioactive materials from the residues of the plutonium factories. So intense is the radiation from these residues that no human being could approach them and live. Consequently, it will be necessary to devise methods of chemical manipulation which can all be operated safely from a long distance and behind thick screens. At present the residues mostly run away as waste.

When an atomic bomb explodes, the neutrons which escape produce intense ionization in the bodies of any human beings in the vicinity, ionization which would lead rapidly to death. Apart from victims at Nagasaki and Hiroshima, several workers of the atomic bomb teams lost their lives through accidents which occurred in the experimental stages. Moreover, apart from the neutrons emitted during and for a short period after the explosion, the products continue to give out lethal quantities of beta- and gamma-rays for some time, unless provision is made for quick dispersal.

It is, of course, conceivable that deliberate use might be made in war of these fission products, in the form of poison gas, or poison powder. Since such materials could be produced as a by-product not only from a plutonium factory but also from an atomic energy plant, it would be difficult for any international authority to police any regulation forbidding their use. It would be exceedingly difficult to combat such a weapon if used in large quantities on a limited target.

BENEFITS FROM THE PILE.

Fission products can be obtained from a plutonium factory, or an atomic energy plant, without disturbing the operation of the plant. Certain other radioactive materials which have great possibilities for the treatment of disease can also be obtained from these installations but *at the cost of a slight reduction of the output of plutonium* or of industrial power, respectively. Two of these products should be especially useful, *radiocobalt* and *radiophosphorus*. Radiocobalt can be made from ordinary cobalt by inserting pieces of that metal into positions near the uranium undergoing fission in the atomic energy plant. Radiocobalt gives out mainly gamma-rays and seems to have certain technical advantages over radium or radon. It is difficult even to guess at what price it could be produced, since one would have to allow for the loss of plutonium or industrial energy, as the case may be, but there seems to be reason to hope that the price might work out considerably less than the price of a corresponding quantity of radium.

Radiophosphorus gives beta-rays. It has come into prominence on account of its use in a method of treating certain diseases allied to cancer. It can be introduced just like an ordinary drug, either through the mouth or by injection. Radiophosphorus can be made by inserting ordinary phosphorus into suitable positions in an atomic energy plant. Here again, it is still problematical what the cost will work out at.

THE ATOMIC ENERGY ACCUMULATOR.

In this connection, I should like to mention an interesting suggestion made, I think, by Gamow[15]. Dealing with the question which people usually ask—how soon will they be able to run their cars on atomic energy—he pointed out that although an atomic energy plant using uranium could not conceivably be fitted to an ordinary car—not only because of the minimum size required for the process to work, but also because of the deadly character of the radiations coming out of it—yet it might be possible to use a large pile of uranium and graphite to charge a sort of atomic energy *accumulator* which could then safely be applied to the motor car. If, for example, we placed a considerable quantity of phosphorus in a large atomic energy plant, and thus turn it into radiophosphorus, this radiophosphorus could then be removed and would thereafter proceed to liberate atomic energy according to its fixed rules.

Since radiophosphorus gives out only beta-rays, it might be quite safe to use it in a car. The difficulty of such a scheme is that the radiophosphorus gives out energy all the time, whether the car is running or not, and the scheme would be very wasteful. I mention it now, because if some such scheme were adopted, radiophosphorus might become quite a cheap commodity.

RADIOACTIVE TRACERS.

It would be wrong if I left you with the impression that the only applications of artificial radioelements are in the treatment of cancer. There is, in fact, a vast application for artificial radioelements in many branches of medical research and practice, and, indeed, in many fields of research and development quite outside medicine.

This arises from the fact that, with a few exceptions, each artificial radioactive element is exactly similar in its chemical behaviour to an ordinary, non-radioactive, element. Radiophosphorus, for example, is similar to ordinary phosphorus ; that is, they cannot be distinguished by ordinary chemical tests. Again, salt made from radiosodium is indistinguishable chemically from the ordinary salt we use at table, and they move through the body in the same way if they are eaten. But, unlike ordinary salt, it is always possible to locate the radioactive salt in the body at any subsequent time, by looking for the radiations it gives out and finding where they are coming from. It has been found in this way that some of the salt reaches the tips of the fingers within two minutes after being eaten.

In the chemistry of living organisms, whether they be plant or animal, the elements carbon, hydrogen and sulphur all play leading roles. Radioactive varieties of all these elements can be made artificially, and by introducing chemical substances containing radioactive carbon, or radioactive hydrogen, or radioactive sulphur, into an animal or plant, it is possible to trace the subsequent movements of these substances, how they progress through various organs, what chemical changes occur, and so on. A large amount of information as to what goes on in animals and plants has already been obtained in this way. Other radioelements, too, have been used, particularly radiophosphorus. It is not impossible that the key to the problem of cancer may be found in the study of the changing behaviour of cancer cells in relation to phosphorus following on their exposure to gamma-rays. These changes can be investigated by using radiophosphorus as an *indicator* in the way I have just described.

In the study of blood transfusion problems, radioactive iron has proved of considerable value as an indicator. Radioactive iodine, radioactive potassium, etc., etc., have all proved of value in connection with some aspects of physiology. Chemical problems apart from those associated with living matter can also frequently be solved in this way.

Then again, radioactive elements have been used in the study of engineering problems, such as those associated with friction and lubrication, and there are also applications in metallurgy.

EPILOGUE.

But it would take too long to detail all the existing and projected applications of atomic energy, and I have already spoken long enough. The applications are both good and bad ; good in the benefits to the sick and in the provision of industrial power ; bad in the terrible destruction that atomic energy can produce. The people of the world have powers in their hands now, the like of which was never dreamed of when most of us here were born. Let us pray that they will have the wisdom to use these powers for good and not for evil.

REFERENCES.

[1] Rutherford, E.,	Phil. Mag., Vol. 21, p. 669 (1911).
see also Rutherford, Chadwick & Ellis,	" Radiation from Radioactive Substances, Chap. 8 (Cambridge, 1930).
[2] cf. Rice, J.,	" Relativity," Chapter 3 (Longmans, 1923).
[3] Smythe, H. D.,	" Atomic Energy for Military Purposes " (Princeton, 1945).
[4] cf. Turner, L. A.,	" Nuclear Fission," Rev. Mod. Phys., Vol. 12, p. 150 (1940).
[5] Seaborg, G. T., et al.,	Phys. Rev., Vol. 71, p. 378 (1947).
[6] Chadwick, J.,	Nature, Vol. 159, p. 421 (1947).
[7] Bostrom, K. J., et al.,	Nature, Vol. 144, p. 830 (1939).
[8] Oliphant, M. L. E.,	Seminar at Canberra, 1947.
[9] cf. Aebersold, P. C.,	Radiology, Vol. 39, p. 513 (1942).
[10] cf. Aston, F. W.,	" Mass Spectra and Isotopes " (Arnold, 1941).
[11] cf. Mayneord, W. V.,	Proc. Phys. Soc., Vol. 54, p. 405 (1942).
[12] Commonwealth Dept. of Health,	" Physical Aspects of Radium and Radon Therapy " (Canberra ; Govt. Printer, 1939).
[13] Low-Beer, B. V. A., et al.,	Radiology, Vol. 39, p. 573 (1942).
[14] cf. Sievert, R. M.,	Brit. Journ. Radiology, Vol. 20, p. 306 (1947).
[15] Gamow, G.,	" Atomic Energy " (Cambridge, 1947).
[16] cf. Wilson, D. W., et al.,	" Preparation and Measurement of Isotopic Tracers " (Edwards, Ann Arbor, 1946).